

CDF - The Top Quark Forward Backward Asymmetry

Yen-Chu Chen

Institute of Physics, Academia Sinica, Taiwan, ROC

Abstract. It has been more than 15 years since the discovery of the top quark. Great strides have been made in the measurement of the top quark mass and the properties of it. Most results show consistency with the standard model. However, using 5 fb^{-1} data, recent measurements of the asymmetry in the production of top and anti-top quark pair have demonstrated surprisingly large values at CDF. Using 4 fb^{-1} data, D0 also has similar effect.

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INTRODUCTION

The forward-backward asymmetry, A_{fb} , of the top quark pair production are studied by both D0 [1] and CDF [2] in 2008. Recently the physics of top quark has become very interesting since the finding of the forward-backward asymmetry, A_{fb} , in the top quark production has become more significant.

At leading order of QCD there is no asymmetry in the top quark pair production due to the Charge symmetry. The asymmetry can arise only in the next to leading order, where interference occurs between the Born amplitude and two-gluon intermediate state as well as the gluon bremsstrahlung and gluon-(anti)quark scattering into $t\bar{t}$. This asymmetry is predicted to be about 0.078 [5] [6] [7]. Recent calculation based on next next to leading order shows $0.052^{+0.000}_{-0.006}$ [8].

At CDF using events having one high transverse momentum lepton and multiple jets, the corrected parton level asymmetry is 0.158 ± 0.074 . Recent analysis using the events having two high transverse-momentum leptons and multiple jets shows that at the parton level the obtained A_{fb} is $0.42 \pm 0.15(stat) \pm 0.05(sys)$. Both results show interesting deviation from the theoretical predictions.

The differential cross section of top quark pair is dependent on the production angle and the Q value of the production. That means the forward-backward asymmetry is dependent on Δy_t and $M_{t\bar{t}}$, where Δy_t is the rapidity difference of the top and anti-top quarks, and $M_{t\bar{t}}$ is the invariant mass of the top, anti-top quark pair. Using the lepton plus jets events, for $M_{t\bar{t}} \geq 450 \text{ GeV}/c^2$, the parton level asymmetry is $0.475 \pm 0.114(stat + sys)$ to be compared with the next-to-leading order QCD prediction of 0.088 ± 0.013 .

THE ANALYSIS

The events used in the analysis are collected by the Collider Detector Facility (CDF) at the Fermi National Accelerator Laboratory [3] [4]. The relevant components to this analysis are the silicon tracker, the central outer tracker, the electromagnetic and hadronic calorimeters, the muon detectors, and the luminosity counters.

At the Tevatron the top quark pairs dominantly are produced via quark anti-quark annihilation, 85%, and from gluon fusion, 15%. The top quark decays almost exclusively to a W -boson and a b quark. Where the W -boson can decay leptonically or hadronically. Based on how the W -boson decays the events are categorized. For the events having only one W -boson decays leptonically, there are one charge lepton, two light quarks and two b quarks in the final state. These are the lepton plus jets events. For the events having both W -bosons decay leptonically, there are two charge leptons and two b quarks in the final state, these are the di-lepton events. In case of both W -boson decay hadronically, these are the all hadronic events. The all hadronic events are dominated by QCD background and are not used in this analysis.

Using the lepton plus jets events

For this analysis the event is triggered by a high transverse momentum electron(muon) in the central portion of the detector with $E_T(p_T) > 20$ GeV(GeV/c) and $|\eta| < 1.0$. The jets originated from quarks are reconstructed using a cone algorithm with $\delta R = \sqrt{\delta\phi^2 + \delta\eta^2} < 0.4$. Four or more jets are required with $E_T > 20$ GeV and $|\eta| < 2.0$. Large missing transverse energy is required, $\cancel{E}_T, \geq 20$ GeV to reduce the QCD background. To further reduce the background, the SECVTX algorithm is used to find displaced b -decay vertices using the tracks within the jet cones; at least one jet must contain such a vertex. From data corresponding to an integrated luminosity of 5.3 fb^{-1} 1260 events pass the event selection.

Given the lepton, missing E_T , and four or more jets, possible combinations are tried to calculate the χ^2 , constraint by the top mass and W -boson mass. The most probable solution is chosen to calculate the rapidity of the top and anti-top quarks, y_t and $y_{\bar{t}}$. Distribution of $\Delta y = y_t - y_{\bar{t}}$ is shown in FIGURE 1. The observed A_{fb} from CDF is 0.057 ± 0.028 , where the uncertainty includes statistical, systematic, and theoretical uncertainties. With the contribution from the background subtracted this becomes 0.075 ± 0.037 . Which is consistent with the measurement from D0, 0.08 ± 0.04 . Taking into account the detector acceptance, reconstruction smearing, the parton level asymmetry can be obtained as 0.158 ± 0.072 .

The differential production cross section of top quark pair is dependent on the production angle and the Q value. This means A_{fb} is dependent on Δy and $M_{t\bar{t}}$. FIGURE 2 shows the dependence on Δy , where larger asymmetry is observed at larger Δy . FIGURE 2 shows the dependence on the $M_{t\bar{t}}$. When $M_{t\bar{t}} > 450 \text{ GeV}/c^2$ the asymmetry is particularly large, $0.475 \pm 0.114(stat + sys)$; which is not consistent with the QCD NLO prediction, 0.088 ± 0.013 .

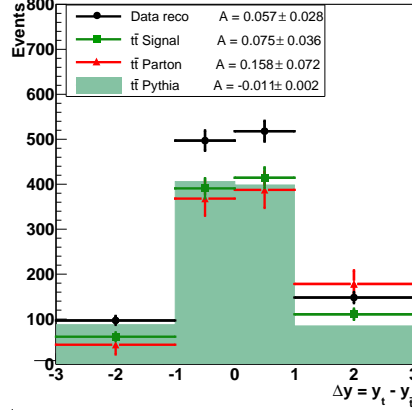


FIGURE 1. The rapidity difference of top and anti-top quark from candidate events.

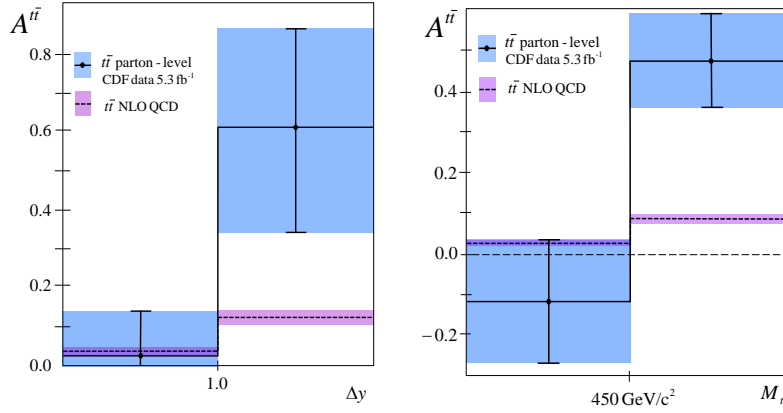


FIGURE 2. Asymmetry dependence on Δy and $M_{t\bar{t}}$.

Using the di-lepton events

The di-lepton events are selected when there are two leptons with high transverse momentum, $p_T > 20$ GeV/c. At least one lepton is from the central portion of the detector. Jets are reconstructed with cone size of 0.4. Two or more jets with $E_T > 15$ GeV and $|\eta| < 2.5$, should appear in a given event. To reduce the QCD background we require high missing transverse energy, $E_t > 25$ GeV or $E_t > 50$ GeV if there is any lepton or jet closer then 20° with respect to the E_t . To further reduce the background additional requirement is placed on the scalar sum (H_T) of the transverse energy of the leptons, E_t , and jets, $H_T > 200$ GeV. From data of 5.1 fb^{-1} 334 events pass these criteria.

To study the asymmetry we plot the pseudo-rapidity difference of the two leptons, which is highly correlated with the difference of the rapidity of the top and anti-top quarks. This is shown in FIGURE 3. The raw asymmetry is calculated to be $0.14 \pm 0.05(stat)$.

The event candidates are reconstructed using a likelihood method. With given assumed pairing of lepton and jet from the same top decay, top quark mass, W boson

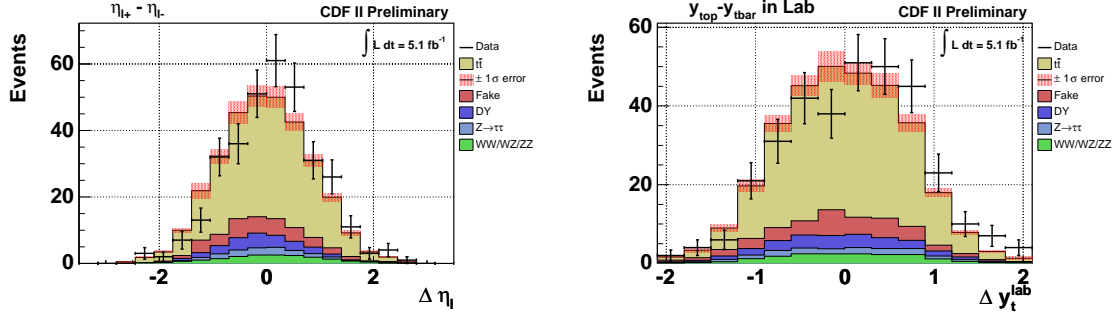


FIGURE 3. Left: The difference of the pseudo-rapidity of the two leptons in the same event. Right: The rapidity difference of the top and anti-top.

mass, the momenta of the neutrinos can be calculated with the constraint of missing transverse energy. $P_z^{t\bar{t}}$, $p_T^{t\bar{t}}$, and $M^{t\bar{t}}$ are calculated and compared to the distributions from the MC study. Jet energy and missing transverse energy are also allowed to fluctuate within the resolutions. Solution is chosen based on the best likelihood value. For the solution chosen rapidities of top and anti-top quarks are calculated. The difference is shown in the FIGURE 3. The raw asymmetry is $0.14 \pm 0.05(stat)$. With background subtraction this becomes $0.21 \pm 0.07(stat) \pm 0.02(background\ shape)$. Converting this to the parton level, taking into account the detector acceptance and the reconstruction efficiency, the true asymmetry is measured to be $0.42 \pm 0.15(stat) \pm 0.05(sys)$.

CONCLUSION

Using 5 fb^{-1} data CDF has done the measurements of the top anti-top pair production asymmetry study in both lepton plus jets and di-lepton channels. Both measurements show significant deviation from the QCD NLO predictions. Many theories have been proposed to explain it. With more data analyzed in the near future this study could further strengthen the results and try to identify the physics that causes this.

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